Overview of Ocean Bottom Detector project

Hiroko Watanabe,
Research Center for Neutrino Science,
Tohoku University

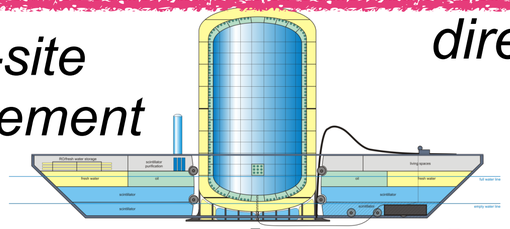
January 3, 2025

Neutrino Geoscience: Current and Future

what we need

improved accuracy of measurement & modelling

multi-site measurement



directional sensitive detector

new type detector

detector in the Ocean

current generation → **next** generation

first measurement in **2005**

total radiogenic heat in the Earth — ☑ Measuring

Th/U ratio — ☑ Measuring

Directly

Next Target!

distinguishing mantle contribution — ☑ Measuring

resolving vertical and horizontal flux differences

detecting K geo-neutrino

what we learn

OBD: breakthrough beyond modern land-based detector transforming our vision of deep Earth

Multi-site Measurement + OBD

Observation = **Crust** + **Mantle**

(y = x + b)

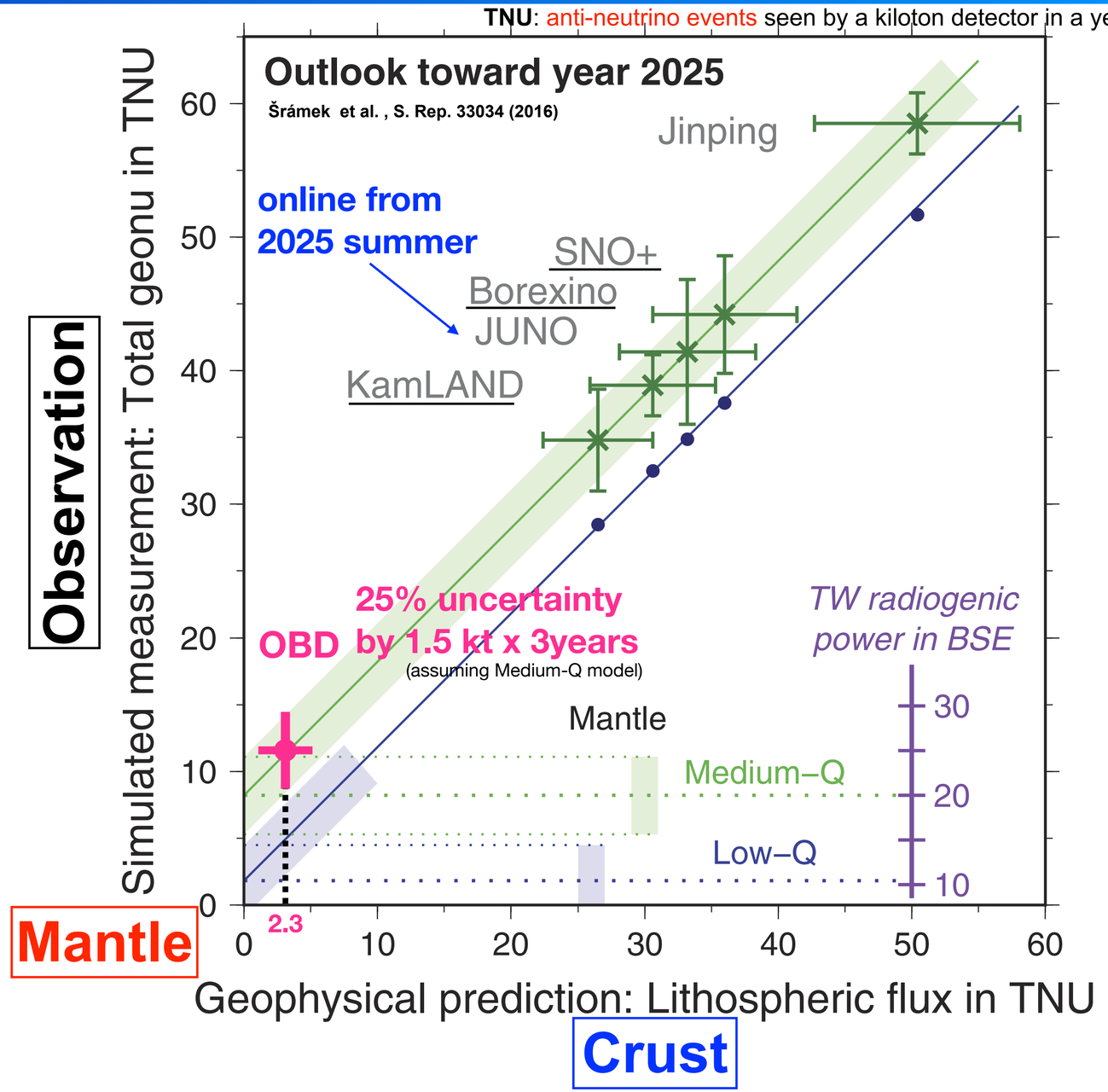
Near Future…

4 multi-site measurements can constrain mantle contribution.

Crust estimation needs to be accurate.

+ OBD

OBD can directly measure mantle contribution.



OBD Motivations

- **Direct Measurement of Mantle**

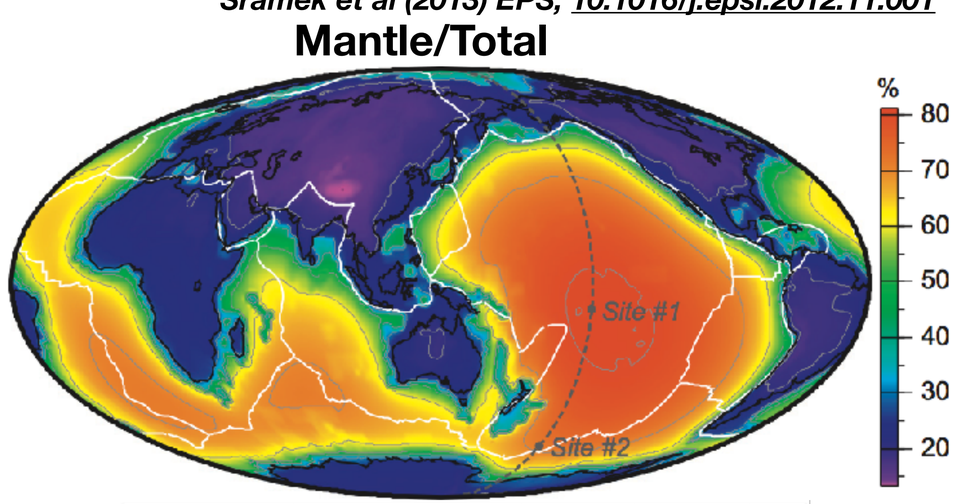
  need to be far from crust
  can be far from reactors

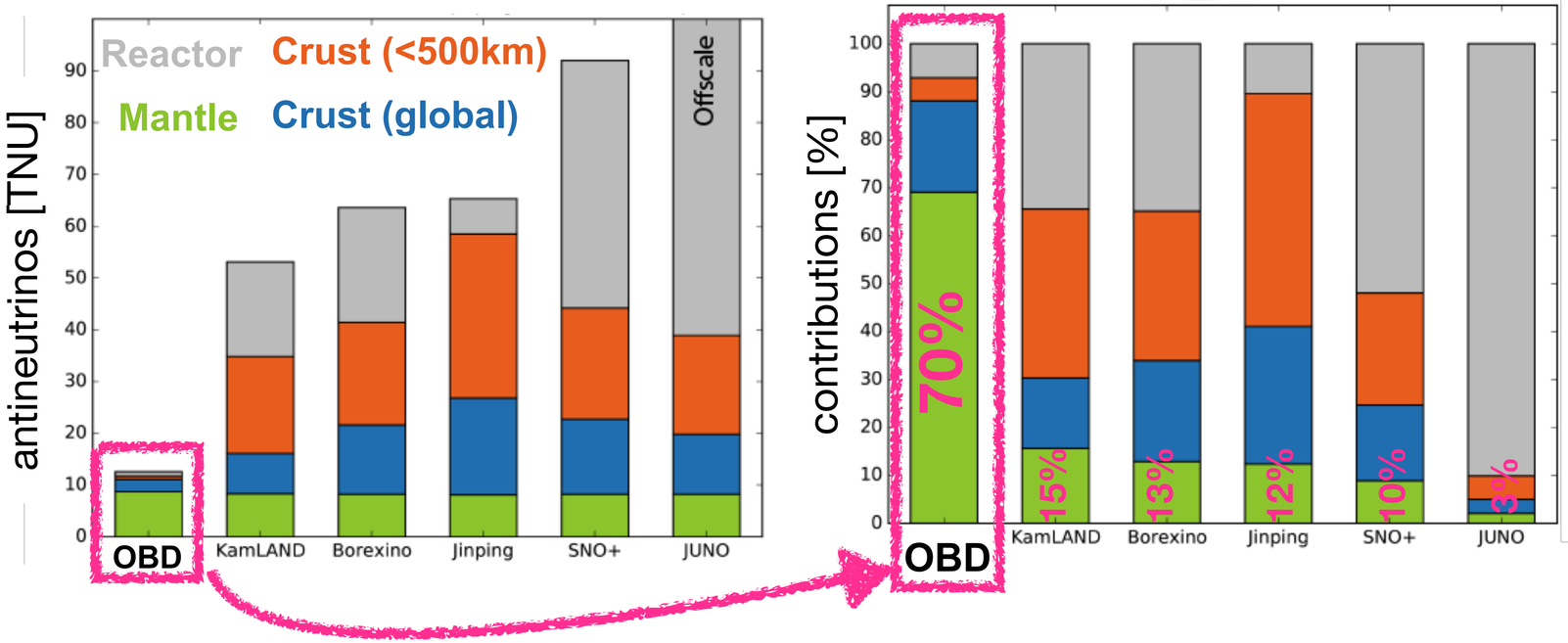
- **Multi-site Measurements**

  Solve the mystery of deep Earth!
  First detector for mapping the inhomogeneous mantle

- **Multidisciplinary Detector**

Šrámek et al (2013) EPS, 10.1016/j.epsl.2012.11.001





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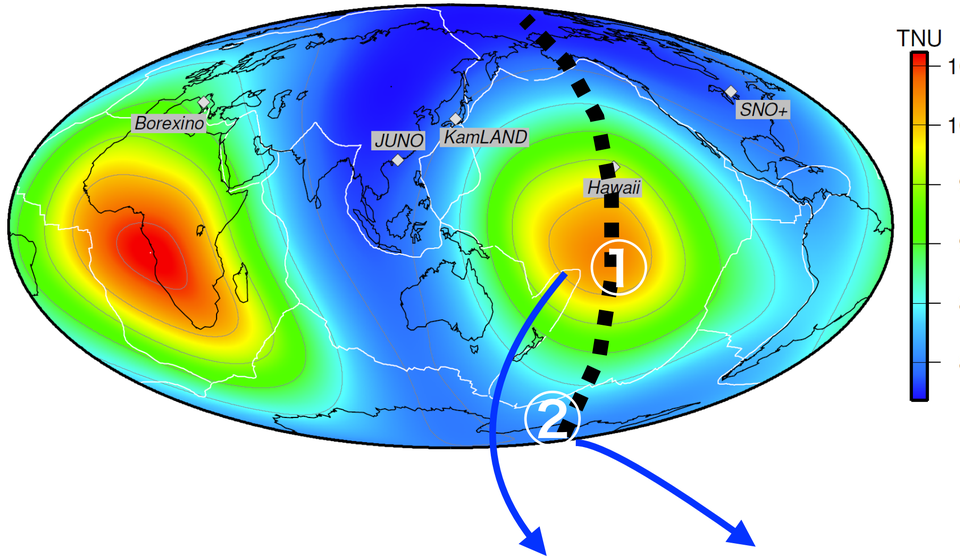
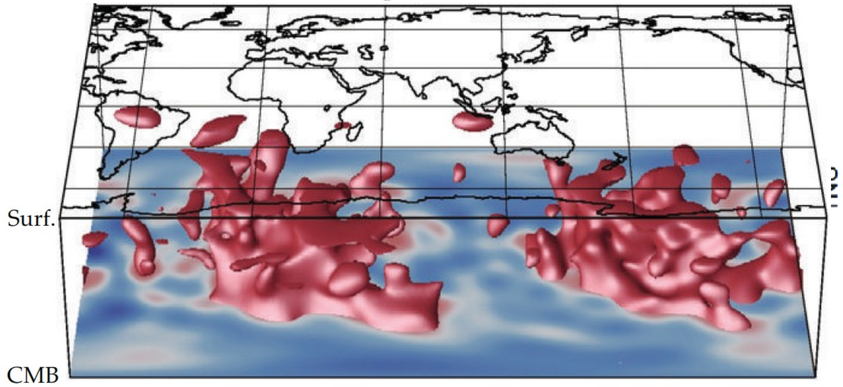
Mantle Geoneutrino Flux

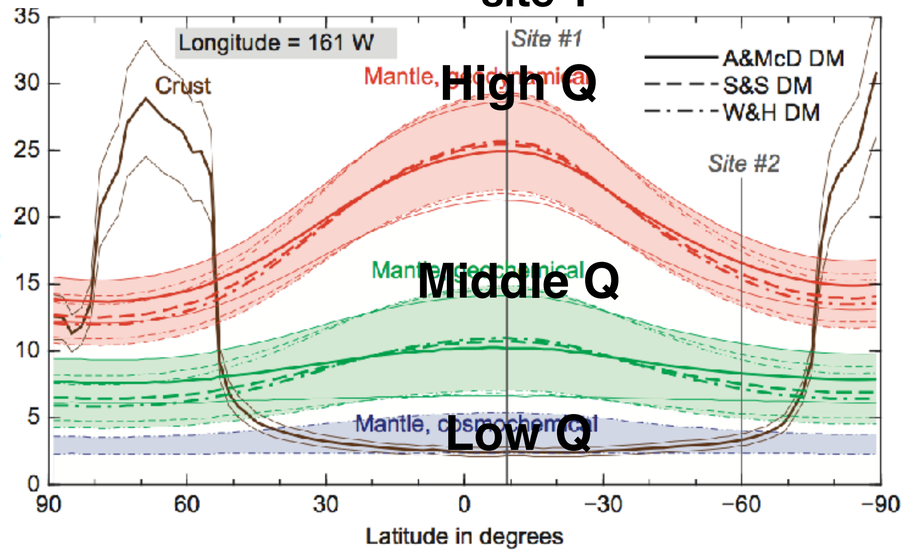


site 1 site 2

Seismically slow "red" regions in the deep mantle



From Alan McNamara after Ritsema et al (Science, 1999)



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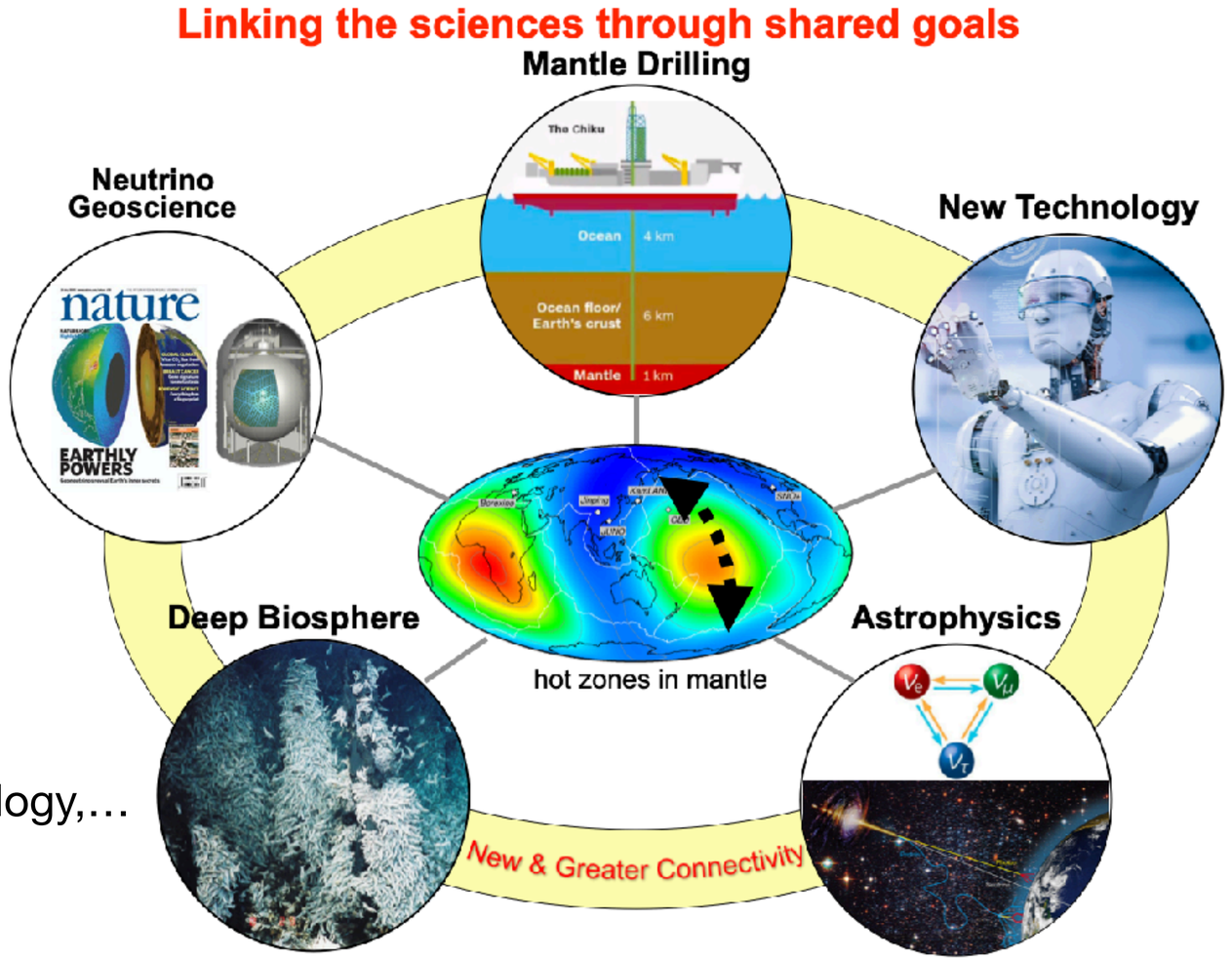
- **Multidisciplinary Detector**

  Physics, Geoscience, Mantle drilling, Biology, New technology,…



OBD Present & Future

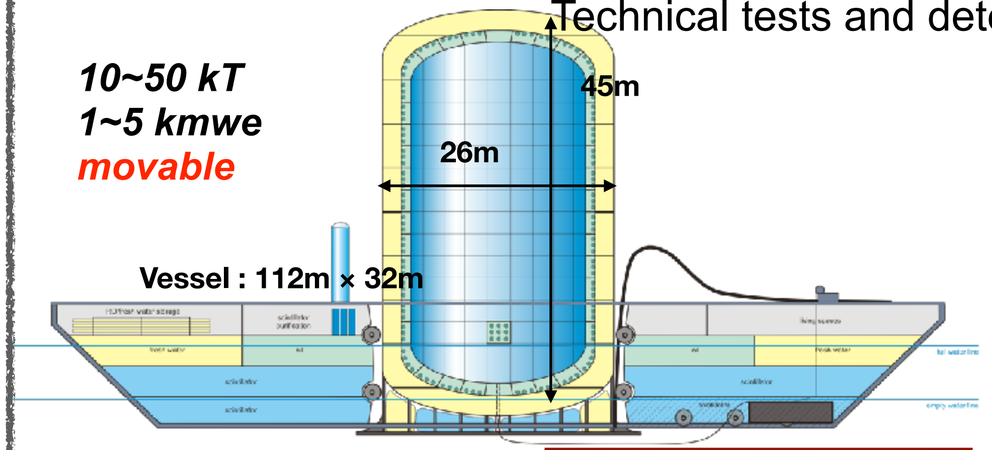
2005 not so many progress… **2019** we are here **2020-2025**

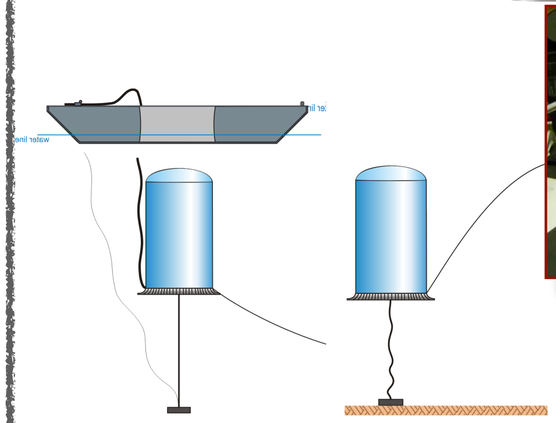
~20 kg | 1-10 t | ~1.5 kt | 10-50 kt

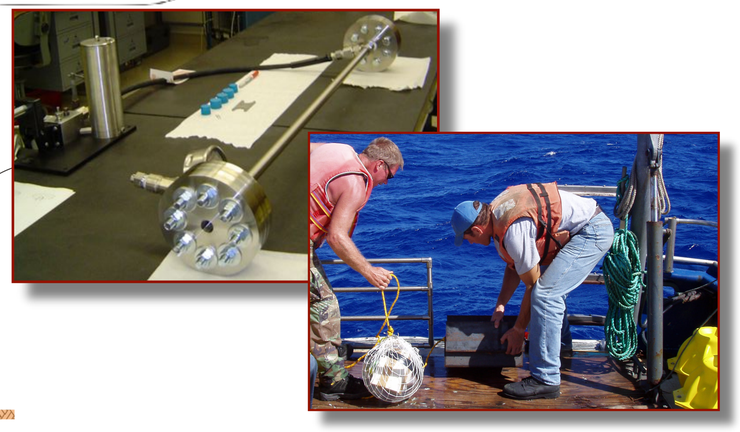
“Hanohano” 2005 U. Hawaii & Makai Ocean Engineering

Technical tests and detector design

10~50 kT
1~5 kmwe
movable

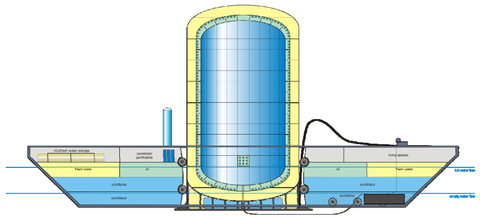






A Deep Ocean Anti-Neutrino Detector near Hawaii - Hanohano

Final Report



Prepared for:

The National Defense Center of Excellence for Research in Ocean Sciences (CEROS)
73-4460 Queen Kaahumanu Highway, Suite 111
Kailua-Kona, Hawaii 96740

Prepared by:

MAKAI OCEAN ENGINEERING, INC.
Waimanalo, Hawaii 96734
http://www.makai.com

and

DEPARTMENT OF PHYSICS AND ASTRONOMY
University of Hawaii, Manoa

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arXiv > hep-ex > arXiv:0810.4975v1

Search... Help | Advanced

High Energy Physics – Experiment

[Submitted on 28 Oct 2008]

Hanohano: A Deep Ocean Anti-Neutrino Detector for Unique Neutrino Physics and Geophysics Studies

John G. Learned, Stephen T. Dye, Sandip Pakvasa

The science potential of a 10 kiloton deep-ocean liquid scintillation detector for ~1 MeV energy scale electron anti-neutrinos has been studied. Such an instrument, designed to be portable and function in the deep ocean (3–5 km) can make unique measurements of the anti-neutrinos from radioactive decays in the Earth's mantle. This information speaks to some of the most fundamental questions in geology about the origin of the Earth, plat e tectonics, the geomagnetic field and even somewhat indirectly to global warming. Measurements in multiple locations will strengthen the potential insights. On the particle physics side, we have identified a unique role in the study of anti-neutrinos from a nuclear power complex, at a range of 55–60 km off shore. Not only can precision measurements be made of most neutrino mixing parameters, including θ_{13} (depending on magnitude), but the neutrino mass hierarchy can be determined in a method not heretofore discussed, and one which does not rely upon matter effects. This detector is under active study on paper, in the laboratory, and at sea. An interdisciplinary and international collaboration is in formation, and plans are in motion for a major proposal, to be followed by construction over several years.

Comments: 35 pages, 23 figures. Published in the Proceedings of the Twelfth International Workshop on Neutrino Telescopes, Venice, March 2007
Subjects: **High Energy Physics – Experiment (hep-ex)**; High Energy Physics – Phenomenology (hep-ph)
Cite as: arXiv:0810.4975 [hep-ex]
(or arXiv:0810.4975v1 [hep-ex] for this version)
https://doi.org/10.48550/arXiv.0810.4975

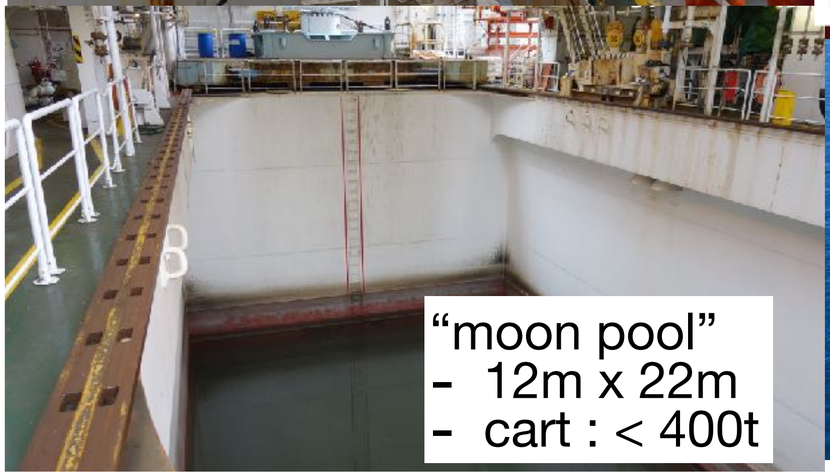
OBD Present & Future

2005 not so many progress… **2019** we are here **2020-2025** *funded*

~20 kg **1-10 t** **~1.5 kt** **10-50 kt**

OBD project has started with JAMSTEC* & Tohoku U.

* Japan Agency for Marine-Earth Science and Technology



Generator
5,000kW×6 2,500kW×2
Equal to the power needed by a town of 10,000 homes (3 kW per home)

OBD Present & Future

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~20 kg **1-10 t** **~1.5 kt** **10-50 kt**

Technical test & world's first measurement in the ocean with LS detector

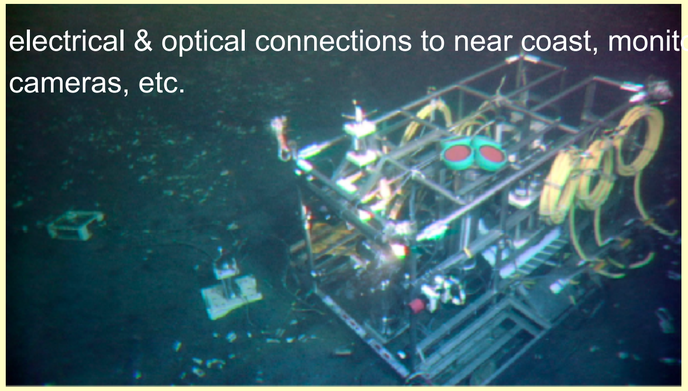
* Install detector into **~1km seafloor** (JAMSTEC's Hatsushima Observatory) take data for **several months**

  Another option: seafloor around Hawaii with battery operation

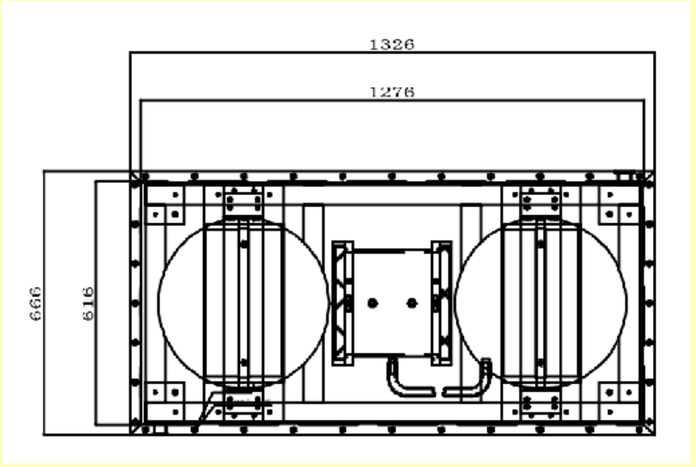
* **measure muon late in the sea → input parameter for future large detector**

* Technical developments are in progress.

Hatsushima Observatory



detector design



OBD Present & Future

2005 not so many progress… **2019** we are here **2020-2025** *funded*

~20 kg → **1-10 t** → **~1.5 kt** → **10-50 kt**

Technical demonstration & environment measurement in the sea

deep sea neutrino & muon flux, ocean water density & temperature, radioactivity

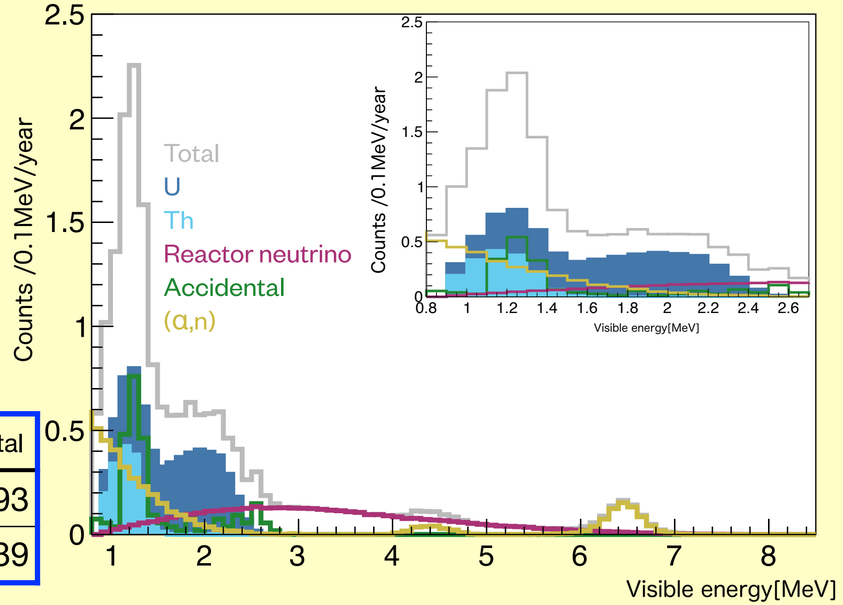
→ input parameters for ~1.5 kt detector design

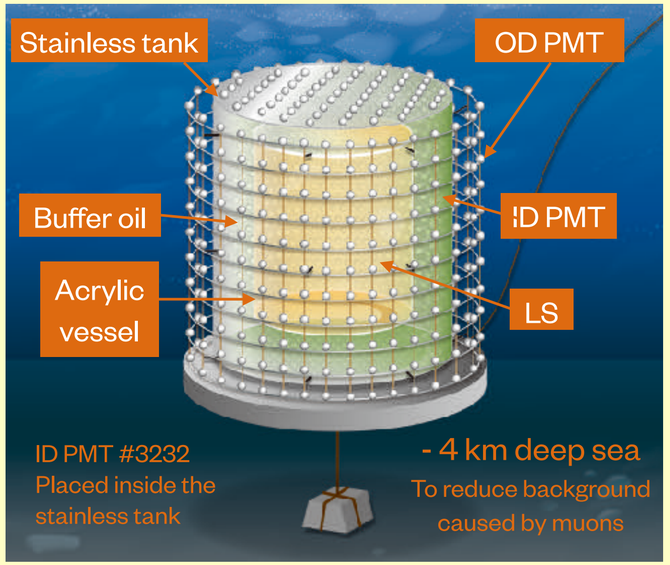
First clear mantle signal

* Detector simulation study is in progress.
* Hawaii is possible position.
* Detector should be installed at **~4km** deep sea to shield muons **Low temperature (2-4°C)** **high pressure (40MPa)**

	Signal			Backgrounds					
E reagion	U	Th	Total	Reactor	Acci.	(α,n)	He-Li	Fast-neutron	Total
All	6.59 (4.61)	1.64 (1.15)	8.23 (5.76)	4.13	1.92	3.88	0	<2.42	9.93
Geo-nu				1.53	1.90	2.96	0	<0.58	6.39

(mantle) **[Events/year]**





* **Mantle geoneutrino sensitivity**

highQ model: 1year → 3.7σ
middleQ model: 3year→ 3.5σ
lowQ model: 10year→ 2.5σ

OBD Present & Future

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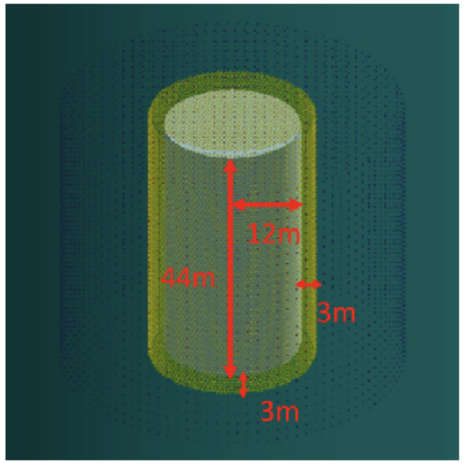
Maturity of science

More statistics, Model separation

17 kt detector simulation

* **Mantle geoneutrino sensitivity**

	LowQ	MiddleQ	HighQ
1.5kt	2.5σ 10 years	3.5σ 3 years	3.7σ 1 year
17kt	3.04σ 1 year	3.94σ 3 months	4.12σ 1 month

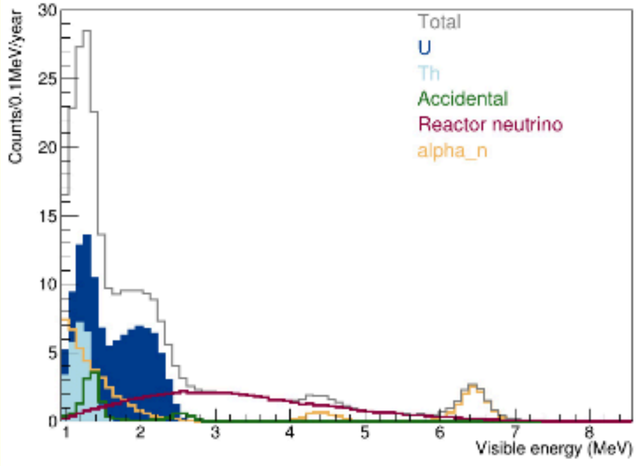


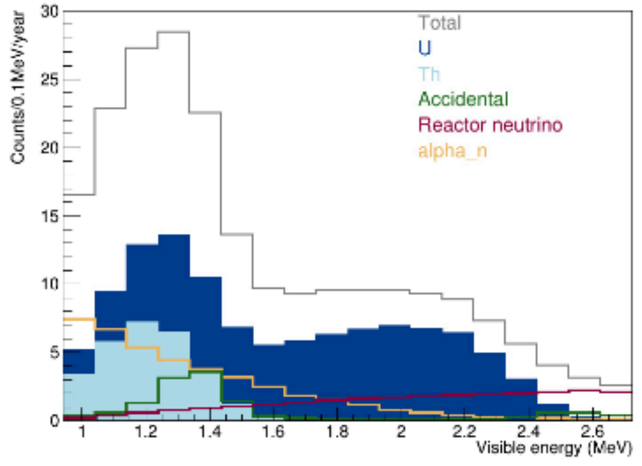
* **Better sensitivity of mantle non-uniformity**

* **Using sea water region for high-energy atmospheric neutrino as “neutrino oscillation tomography” to understand LLSVP**

Signal **Backgrounds**

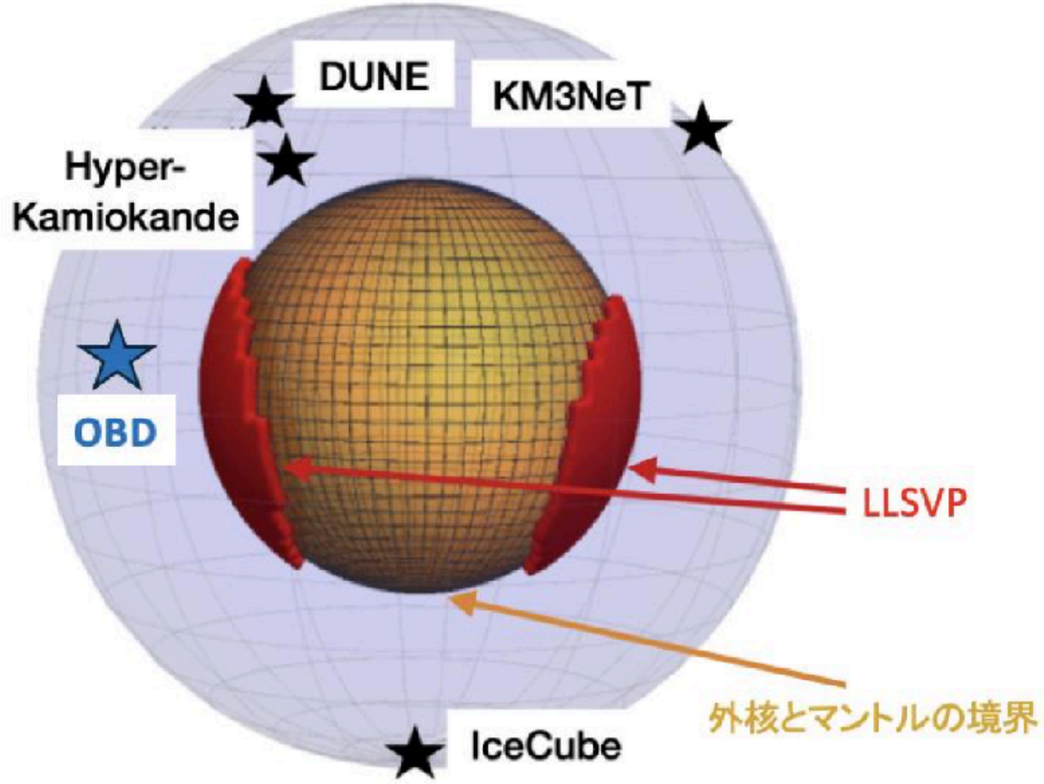
	U	Th	total	reactor	accidental	(α,n)	He-Li	total
全領域	112.45	28.05	140.50	67.84	14.29	55.47	0	137.60
地球ニュートリノ領域				23.08	12.61	40.27	0	75.96
マントル寄与	78.72	19.64	98.36	-	-	-	-	-





* Using sea water region for high-energy atmospheric neutrino as “neutrino oscillation tomography” to understand LLSVP

Pacific Ocean is an unique location just above LLSVP region.
Special opportunity to understand density of deep mantle?



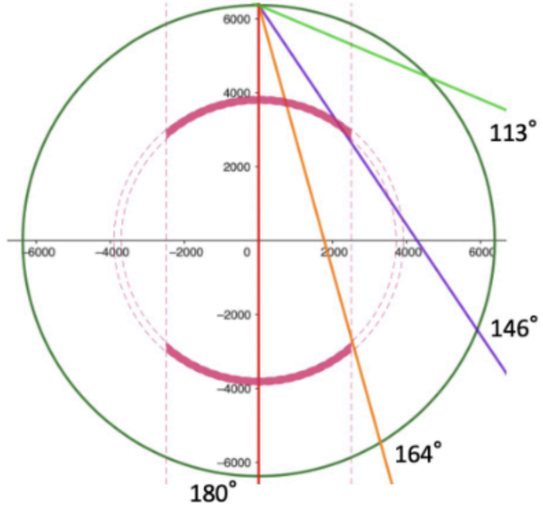


図 6.3: 大気ニュートリノの天頂角ごとの経路

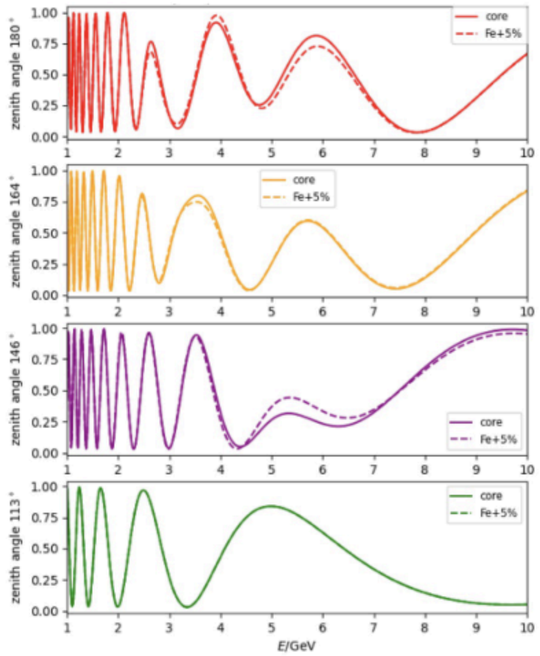


図 6.4: 大気ニュートリノの天頂角ごとのミューニュートリノの生存確率

Cost Estimation

Detector size	running time to identify model	detector cost	ship cost	running cost
検出器サイズ	モデル分別に必要な観測期間	検出器製作費	船の製作費	船の運用費
1.5kt	10 年	48 億円	28 億円	21 億円 ×10 年
17kt	1 年	369 億円	78 億円	57 億円 ×1 年
	years	/1.5 [M$]	/1.5 [M$]	

Detector size	1 position	2 positions	3 positions
検出器サイズ	合計費用 (1 地点)	合計費用 (2 地点)	合計費用 (3 地点)
1.5kt	286 億円 (10 年)	496 億円 (20 年)	706 億円 (30 年)
17kt	504 億円 (1 年)	561 億円 (2 年)	618 億円 (3 年)

- Smaller size detector costs less, but takes longer time to do science
- Detector cost & running cost should be considered

OBD Present & Future

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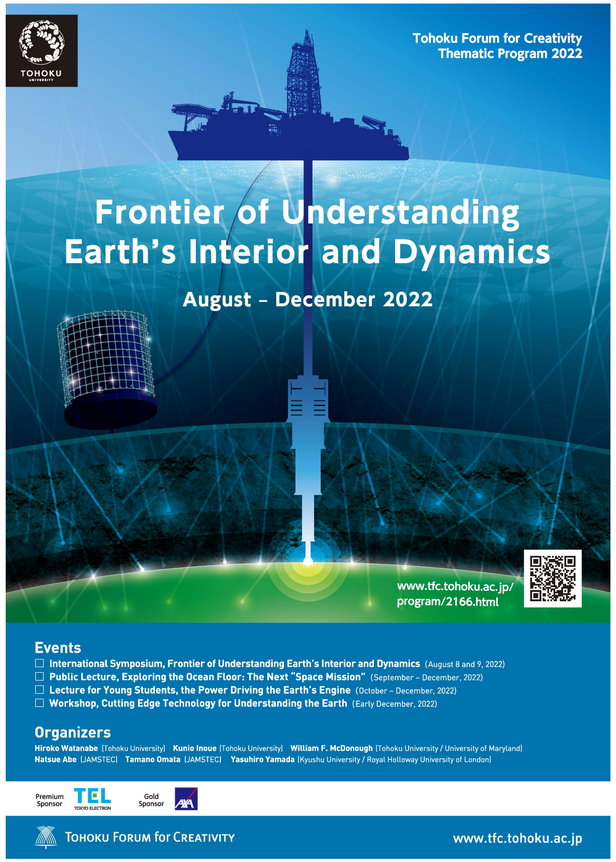
Community Building Status

Thematic Program 2022



international symposiums

outreach @Astronomical Observatory

In total
~60 participants
from different
countries during
the program.

Corporative study with U. Hawaii & LLNL
* discussing idea & plan of research
* applying for funding

Corporative study with IceCube (Chiba U.)
* corporative development of PMT module
(glass shielded PMT & electronics)

Future Science Promotion Initiative 2023 (Science Council of Japan)

105	深海アルゴフロートの全球展開による気候・生態系変動予測の高精度化	神田　穣太（日本海洋学会会長）
106	地球ニュートリノ観測が切り拓く新しい地球未来像	渡辺　寛子（東北大学・ニュートリノ科学研究センター助教）
107	衛星全球地球観測による気候・地球システム科学研究の推進	若林　裕之（日本リモートセンシング学会会長）

Developments & Discussion Lists

on-going, to-do's

For high pressure, low temperature, isolated place

- ✦Glass shield
  - high purity glass
- ✦Liquid scintillator
  - light yield, transparency
  - under high pressure
- ✦PMT module
  - glass shielded PMT & electronics
  - non-PMT idea?
- ✦Electronics, DAQ
  - limited availability of electricity
  - design of DAQ system

details will be presented by following talks

Detector simulation

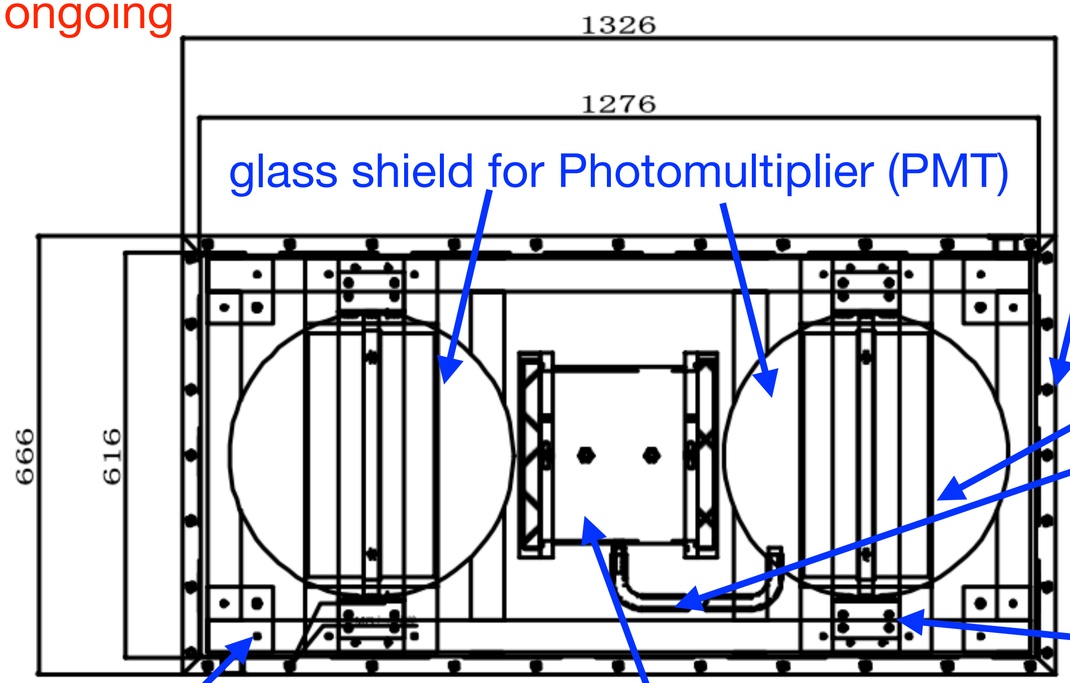
- ✦Prototype detector
  - pressure compatibility check
  - light-transfer simulation
  - physics event simulation
    - muon
    - LS monitoring with calibration source
    - sea water radioactive impurity measurement
- ✦Larger size detector
  - size-depending sensitivity estimation
  - **directionality?**
  - sea water as Cherenkov detector

Project design

- infrastructure for detector
- cost estimation
- funding strategy (time & sources)

Prototype Detector

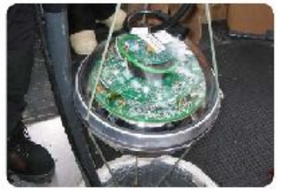
blue: complet
red: ongoing



stainless box

PMT & electronics

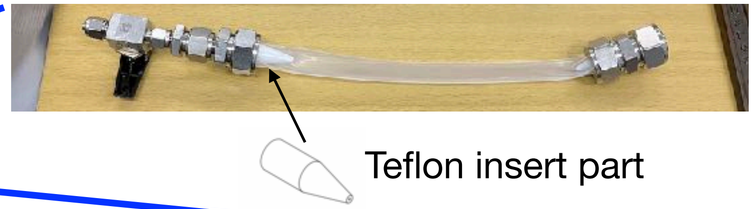
ref) IceCube experiment



pressurize test facility

@Tsurumi Seiki (Yokohama)

pressure compensation tube

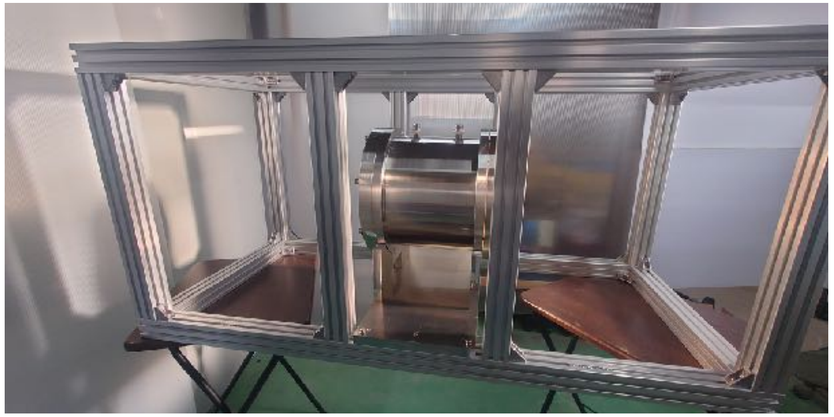


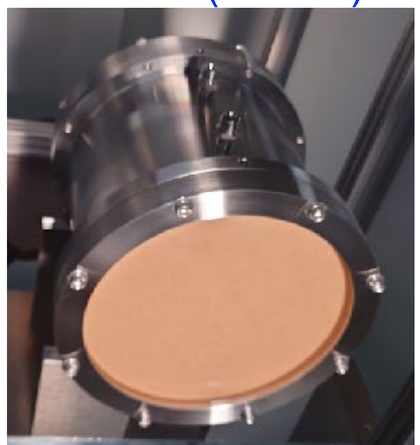
Teflon insert part

flame

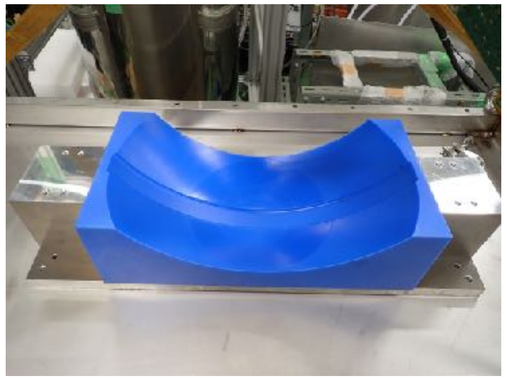
Liquid Scintillator tank (V=30L)

shield folder





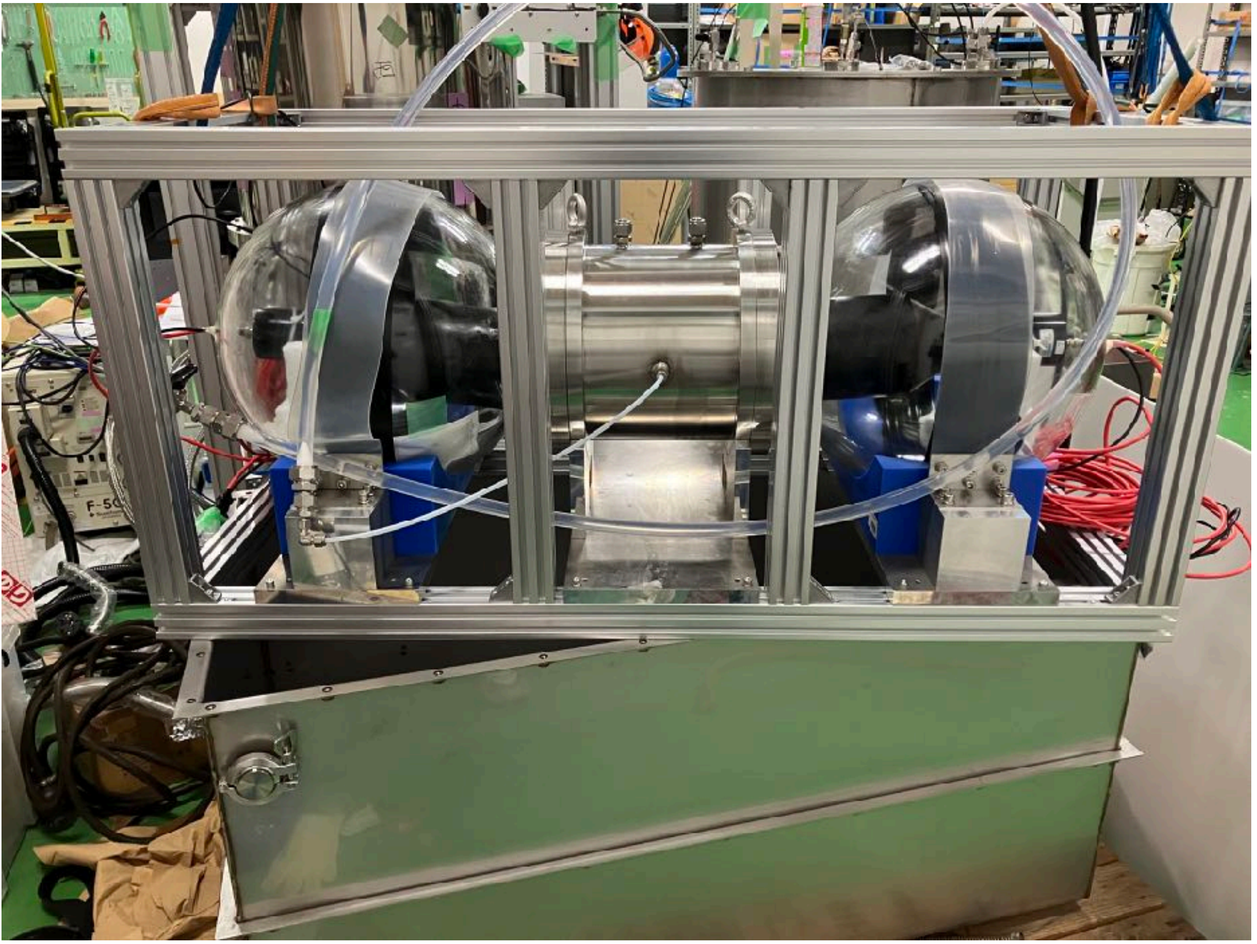
pressurise simulation



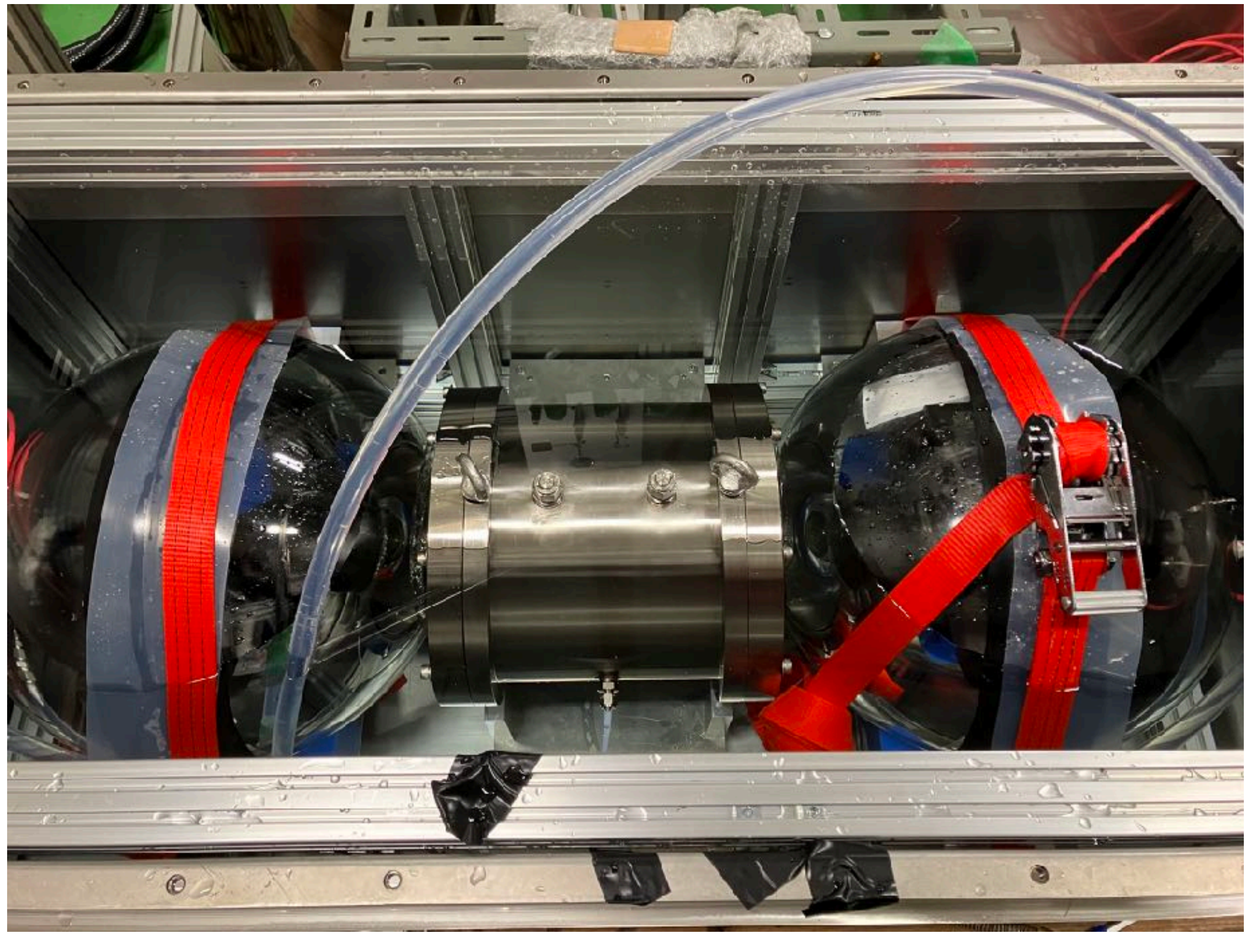
Prototype Detector

Measurement test at Tohoku U.

assembled (5inch PMT with glass shelled)



with water

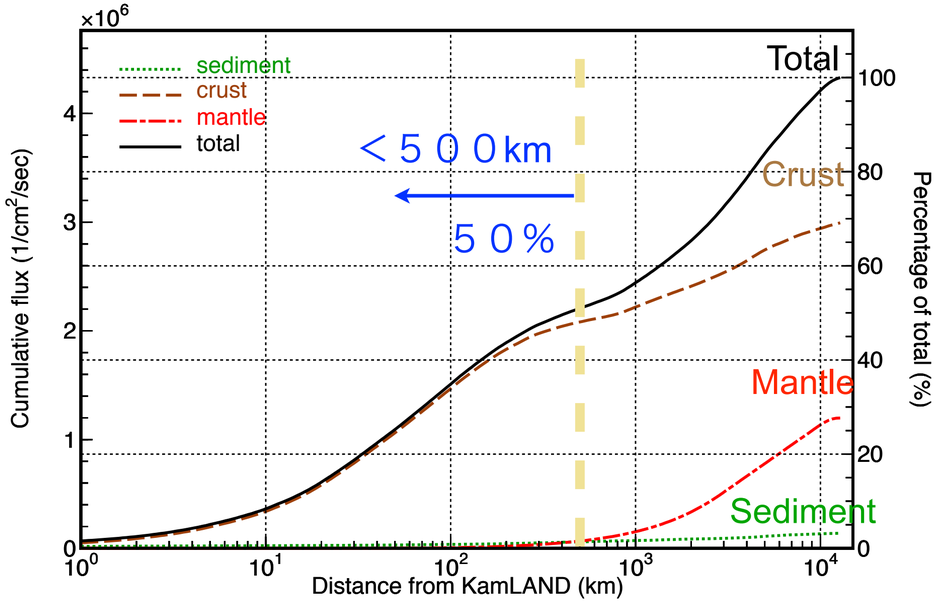


Directionality

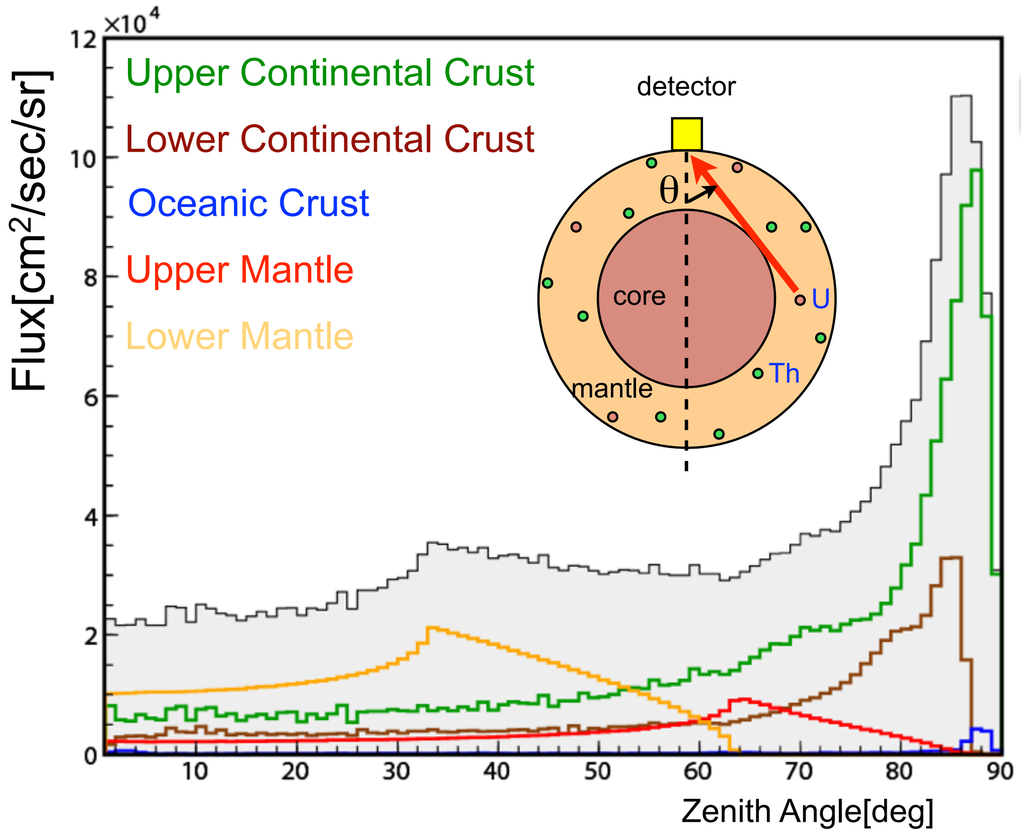
1. large size detector (1kt~)

<u>geo-neutrino</u>

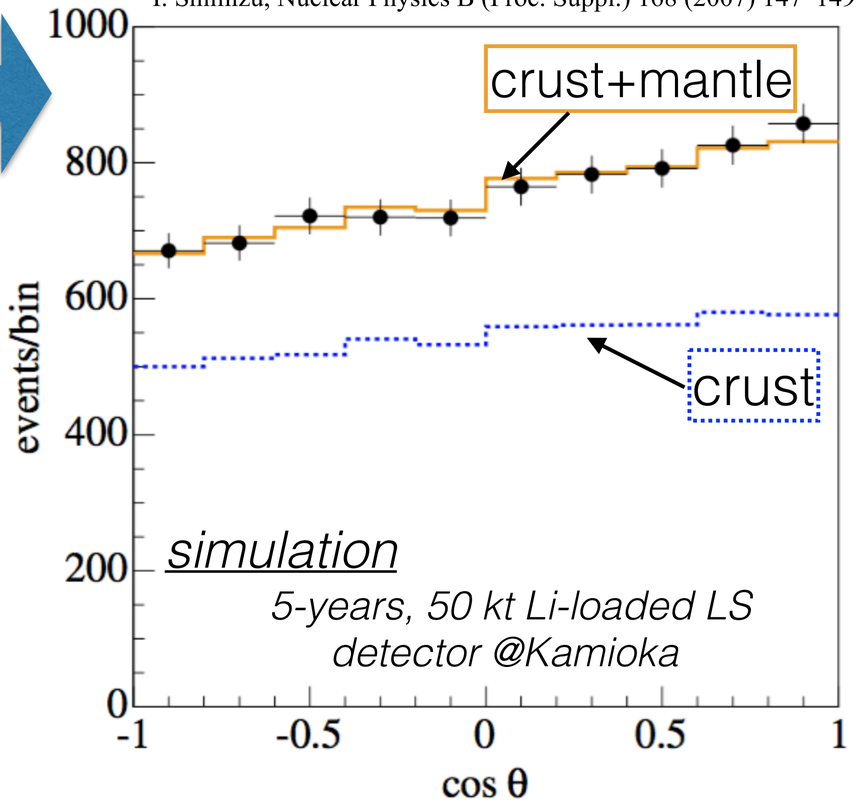
- distinguish mantle from crust contributions
- separate reactor anti-neutrinos



geo-neutrino angular distribution @Kamioka



I. Shimizu, Nuclear Physics B (Proc. Suppl.) 168 (2007) 147–149



Testing a proposed “second continent” beneath eastern China using geoneutrino measurements

arXiv:1810.10914v1

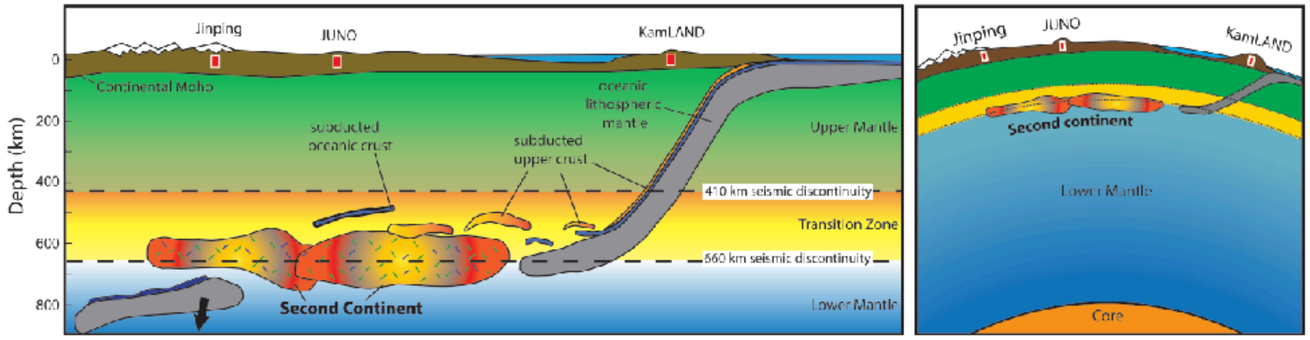
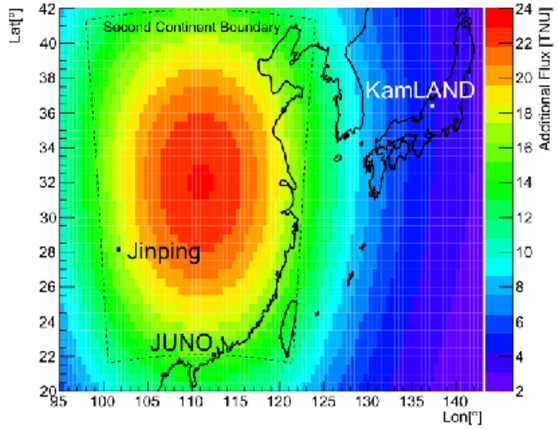
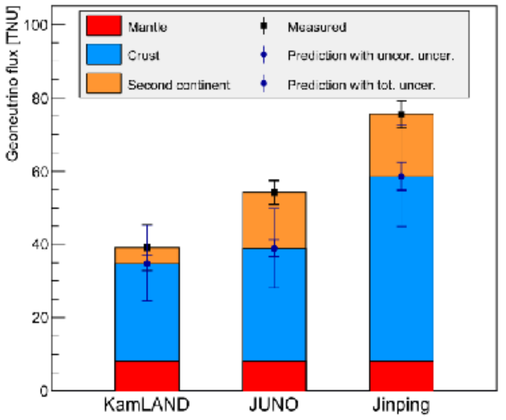
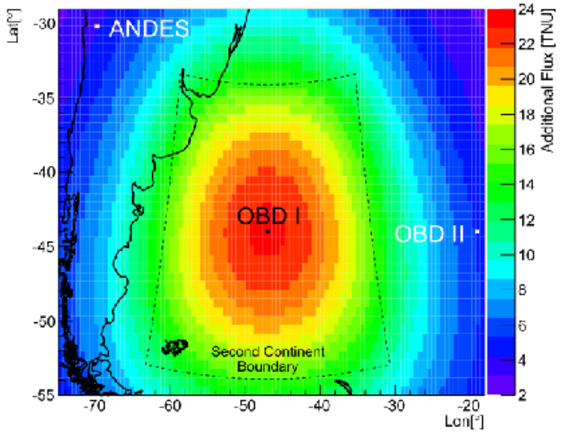
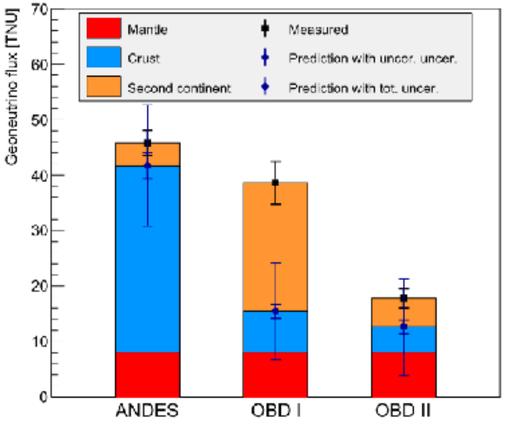


Figure 1. Left panel shows cartoon illustration of a second continent that formed under eastern China due to Pacific-type subduction occurring along the western margin of the Pacific basin. Picture is an adaptation of Fig. 5. in [*Kawai et al.*, 2013]. The proximity of 3 geoneutrino experiments to this putative second continent are shown as being underground in Japan (KamLAND) and China (JUNO and Jinping). These 3 detectors see approximately the same mantle volume and similar global crust, see right panel, which results in a major reduction in the predicted uncertainties. Local differences in the geoenutrino fluxes for each of these detectors are due to geological differences in the nearby lithosphere (closest 500 km) surrounding the detector; this region contributes approximately half of the detected signal.









Status of Technical Developments

✦PMT shield

Needs : low background
pressure resistant

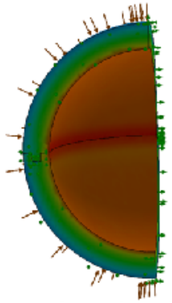
DUMAND, IceCube type
PMT module is expected



Acrylic

- low background
- pressure resistant : <40MPa broken

Pressure test @JAMSTEC



structural calculation

can not be used?

Glass (OKAMOTO Glass Co.)

- pressure resistant
- very high impurities

[g/g]

	^{238}U	^{232}Th	^{40}K
target	1x10^{-8}	1x10^{-8}	1x10^{-8}
normal glass	~1x10^{-7}	~1x10^{-7}	~1x10^{-7}
our work	**1.4x10^{-8}**	**<5.0x10^{-9}**	**3.4x10^{-9}**
reduction	**1/10**	**1/500**	**1/300**

* cleaner material selection
* Pt coating on the melting pot

enhance the size (20 inch)

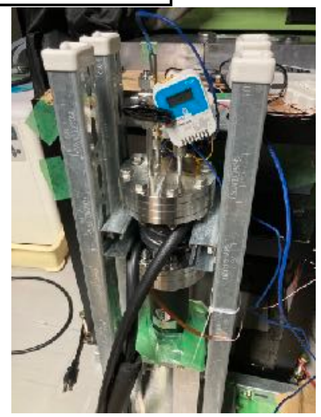
can be used

✦Liquid scintillator

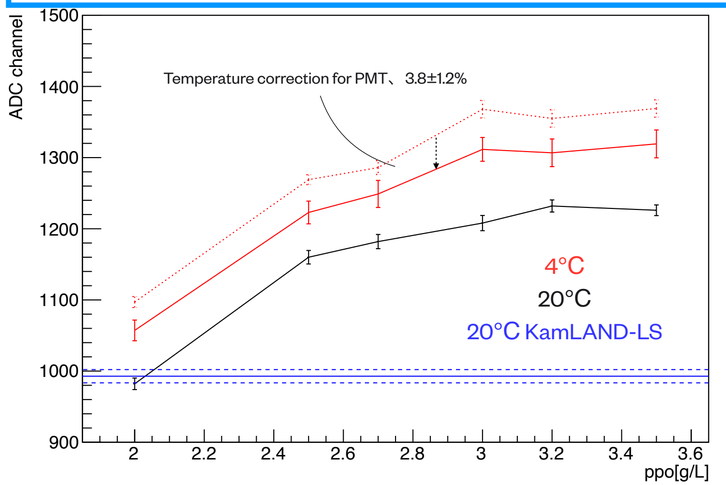
LAB(oil) + PPO(fluorescents)

Low temperature

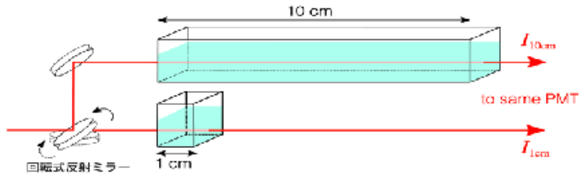
light yield



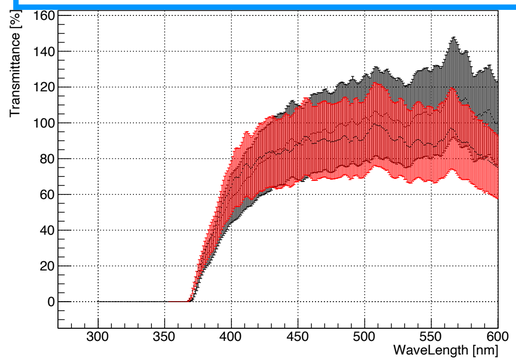
4°C is brighter than 20°C (+9%)



light transition



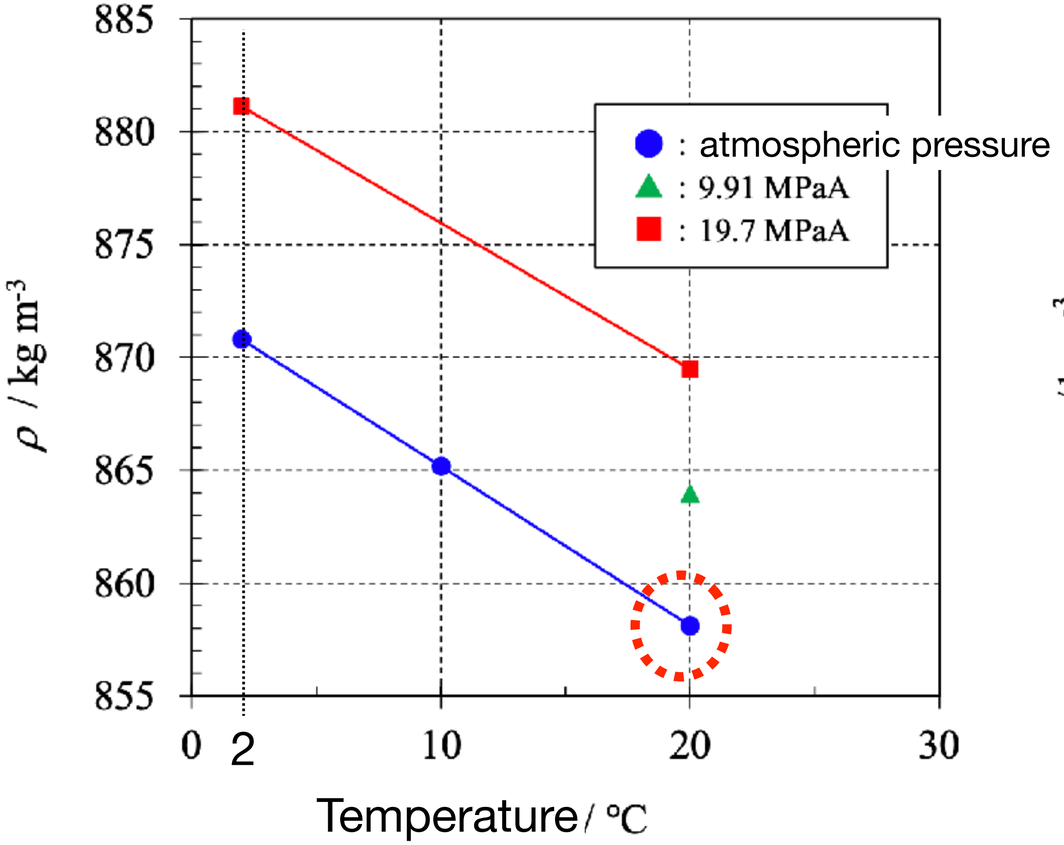
no temperature affect

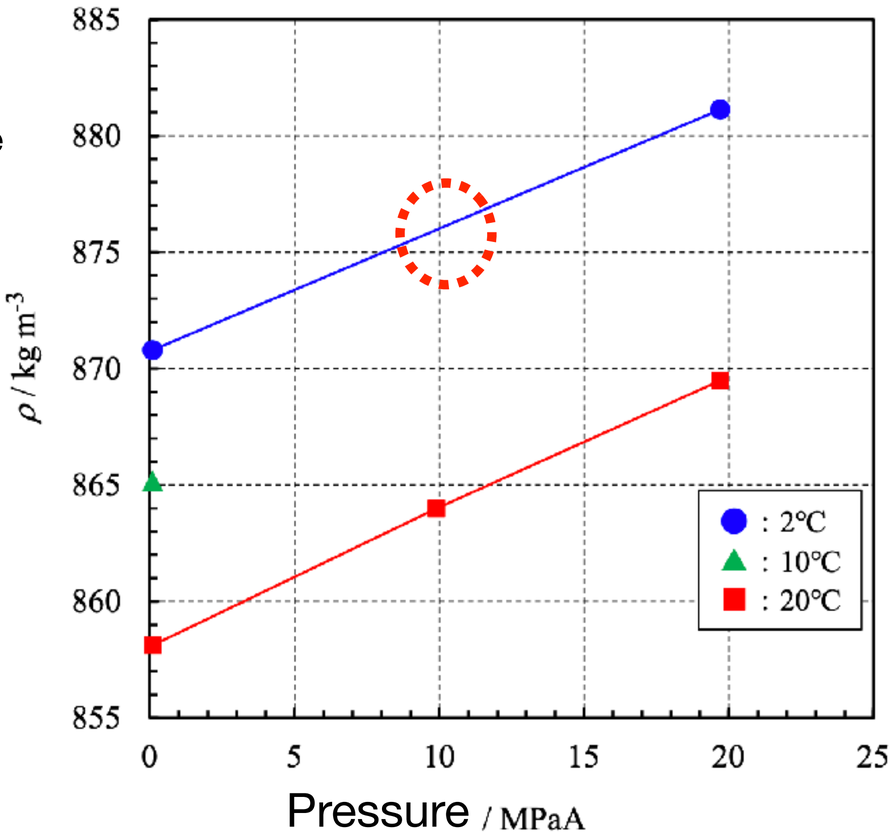


Status of Technical Developments

✦Liquid scintillator density under low-temperature & high pressure

Temperature & pressure dependence profiles are available.





uncertainty : 0.05%

20°C, atmospheric pressure : 858.11 kg/m³

2°C, 10 MPa (1km seafloor) : 876.02 kg/m³ (calculated)

2°C, 40 MPa (4km seafloor) : 891.84 kg/m³ (calculated)

compensation volume

+2.1% → 0.63 L for 30L LS

+3.9% → 68 m³ for 1.5 kt LS